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Keeping Track of the Changing Tactical Picture

by James D. Walrath

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14. ABSTRACT

Graphical displays of the battle space are becoming ubiquitous within today's Army command and control infrastructure. For the unit of action soldier, knowing the position of objects of military interest within that soldier's area of operation is paramount in achieving and maintaining situational awareness. It is important to realize, however, that situational awareness is not a product. Rather, it is a process that involves understanding the spatial relationship and attributes of battlefield entities and how these change with time. The user of a situational awareness display must note the location of symbols and changes in symbol attributes (e.g., variations in speed, direction, relative position) that may require reevaluation of operational plans or threat potential. Previous research has shown that a person's ability to keep track of changes in entity attributes is limited, but in all of those experiments the values of attributes were represented alphanumerically. This paper, based on work by Walrath, Monty, Harper, and Coury (1995), discusses the ability of people to keep track of changes in graphical symbols. The effects of graphical representations on keeping track performance and implications for tactical display decision support are discussed.

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Contents

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Introduction

An effective representation of the evolving tactical picture is critical to the Soldier. Addressing this need are today's tactical displays which use symbols, against a map or image background, to depict objects of military interest. These symbols are often designed to represent more than a single attribute of an entity. Understanding the state of these attributes is important in monitoring operational pace, anticipating problems, and insuring mission success. Since entity attributes and behavior can change over time, the user is very much concerned with noting these changes and understanding their effect on the evolving tactical picture.

Understanding the tactical picture is often referred to as situational awareness (SA). Situational awareness began to receive considerable attention by the research community in the 1980's (Andre, Wickens, Moorman and Boschelli, 1991; Dominessy, Lukas, Malkin, Monty and Oatman, 1991; Fracker, 1988; Sarter and Woods, 1991; Wickens, 1992). Much of this earlier work focused on cockpit displays for aviation. Aviation research typically considered SA in terms of the spatial relationship between a pilot and other aircraft in the tactical environment, awareness of the intent or lethality of those aircraft, and knowledge of the current state of the pilot's aircraft.

These same aspects of SA are also relevant to Army operations; the Soldier must understand the relationships among entities in the tactical picture, the intent or lethality of those entities, the current state of readiness of friendly units, and the dynamic characteristics of the situation. Unlike the pilot, however, SA for the Soldier involves other unique aspects: the tactical picture may depend on many sources of remote sensor input; and the tactical picture may be very complex (i.e., military operations in urban terrain).

Awareness of the tactical picture for the Soldier can be characterized in terms of three basic, interrelated components: a temporal component; an expectation component; and a workload component. The temporal component dictates both the rate of change of the tactical picture and the way in which that picture will change. The rate at which the picture changes will be dependent upon the reliability and integrity of the sensor technology, the bandwidth for data communication, and the complexity of the tactical picture. The expectation component captures the operator's belief that an entity will behave in a manner consistent with its classification profile (e.g., one would not expect a tank to traverse a lake). The kinematics of a known entity provide the operator with a model of expected maneuver behavior, and violations of those expectations requires the operator to attend more closely to that entity. The workload component of the tactical picture is related to the number and type of entities to be tracked, the terrain, and time constraints. In a situation where noncombatants can be intermixed with the opposition force (e.g., in the early stages of a regional conflict), the operator may be faced with a very dynamic situation involving a variety of entity types: hostile; friend; neutral; or unknown.

Consequently, changes in the behavior of elements comprising the tactical picture are very important, and the operator must be able to detect and recognize how entity behavior has changed and how these changes effect threat level, synchronization, and operational tempo. In order to determine if a change has taken place after an update in the tactical picture, the operator must search the display and compare the current set of symbols with the antecedent (no longer visible) set, looking for symbols that reflect a change in attributes such as identity (friend, foe, other), speed, direction, or threat level. Thus the operator must visually search the display while "keeping track" of each symbol, across time, in what can be a very dynamic environment.

Keeping Track of Changes in Attributes

Yntema (1963) was one of the first to recognize that a person's ability to keep track of a changing visual display was more than merely recalling information from short term memory. To effectively keep track of a situation, Yntema noted, a person must integrate the information from a sequence of events and remember the latest state of the situation. To determine the effect of monitoring changes in state over time, he conducted a number of experiments in which people were required to monitor objects for a change in an attribute; the number of objects, number of attributes and the rate of attribute update were manipulated as independent variables. His research demonstrated that a person's capacity to keep track of objects and monitor changes in object attributes over time was quite low. Error rates were high when only two or three objects or attributes were monitored, even when the sequence of changes was predictable. Performance was greatly improved, however, when there was a very high correlation among the states of different attributes, implying that people can use the dependencies among variables to aid in keeping track, a result consistent with some of the other research in the processing of visual displays (Buttigieg and Sanderson, 1991; Coury and Boulette, 1992).

Subsequent research supported Yntema's results and provided additional insight into keeping track performance. Monty and his colleagues (Monty, 1968, 1973; Monty and Karsh, 1969; Monty, Taub and Laughery, 1965) demonstrated similar limitations in keeping track performance in a series of experiments that externally paced the rate of change in object attributes and manipulated the number, type and importance of attribute information. The results of those studies indicated that three important factors affect keeping track performance. First, people find it difficult to keep track of changes in as few as three categories of information (Perlmuter, Karsh and Monty, 1976). As the number of categories of information increase beyond two, there is a significant decrement in performance.

Second, the effect of irrelevant information on keeping track performance is dependent upon the regularity of irrelevant events (Monty, Karsh and Taub, 1967). As one might expect, the irregular occurrence of irrelevant information significantly degrades performance by interfering with the rehearsal of information in working memory and making it difficult for a person to anticipate the next relevant event.

Third, performance is affected by the rate of presentation, with slower rates allowing more accurate discrimination between two categories of information and faster rates resulting in a decrement in performance (Taub, Monty and Laughery, 1967). Since the rate of presentation is dependent on both the time the information is available for processing and the time between events, both the stimulus on-time and the interstimulus interval are important. Results indicate that at short interstimulus intervals (one letter per second), the stimulus on time (minimum = 100 ms) does not affect performance. At intermediate rates (1 letter every 2 to 3 s), the fastest stimulus on times optimized performance.

Similar results were obtained by Harwood, Wickens, Kramer, Clay and Liu (1986) in a simulated air traffic control task. In the first experiment, people were required to remember the status of 2, 3, or 6 aircraft that were defined by 1–3 attributes that changed over time. The results indicated that people were best able to keep track of a small number of objects with few changing attributes.

The literature suggests, then, that keeping track is a relatively difficult memory task, and that performance is affected by the number of objects and attributes, the rate of change in attributes, and the importance of attribute information. Unfortunately, all of the previously cited research represented attribute information in an alphanumeric format. There is considerable evidence to suggest, however, that an object-like representation of multidimensional data can enhance the detection and recognition of changes in state (Buttigieg and Sanderson, 1991; Carswell and Wickens, 1987; Sanderson, Flach, Buttigieg and Casey, 1989), especially when the display produces a unique mapping of perceptual cues to a state category (Coury and Boulette, 1992; Coury, Boulette and Smith, 1989). Although Harwood et al., (1986) used the spatial location of an aircraft as a location cue and color coding to indicate related attributes, the values of critical aircraft parameters (altitude, airspeed and heading) were presented digitally. Since many tactical displays represent the attributes of battlefield entities in a graphical format, none of these studies directly comment on the effect of graphical representations or the effectiveness of current tactical symbology on keeping track performance.

Research to address this gap in knowledge was performed by Walrath et al., (1995). Their research had three primary objectives. First, it determined if the factors that had been shown to affect keeping track performance in previous research were relevant to an all symbolic display. Of specific concern was the complexity of the tactical picture, i.e., the density of tracked entities and the number of changing attributes. Second, it determined if graphical representations of entity attributes produced similar effects on keeping track performance as alphanumeric representations. In their experiment, the graphical representations were based on standard U.S. Army symbols.

Finally, their work provided an estimate of the number of symbols that could be tracked without a significant decrement in operator performance. Although situation displays can present information for many more entities than can be kept track of by the user, it was not clear what level of workload was within the capability of the operator. Determining the number of entities that could be tracked and the number changes in entity attributes that could be detected was thought to be particularly important for the design of decision support systems.

Participants in their study viewed a touch-screen equipped computer monitor upon which MIL STD 1477 symbols (air defense symbols) moved about a circular area of interest with the participant's own position in the center and the radius denoting some arbitrary range. Aircraft symbols were located on the display based on simulated bearing and range of that aircraft relative to the observer. Symbol shape denoted the aircraft's threat class and graphical elements, that were part of the shape, indicated the direction of flight and whether the aircraft was a fast mover or a slow mover. Both the number of symbols (2, 4, 6, or 8) and the number of changing symbol attributes (speed, direction, and threat class) were manipulated. Subjects monitored the dynamic display and were asked to detect and note any change in symbol attribute by touching the symbol that had changed.

Discussion

One of the primary objectives of this research was to determine if the keeping track performance found in earlier laboratory experiments was applicable when only graphical symbols were used. The results were consistent with earlier work by Monty (1973); when only two entities (represented by graphical symbols) were present, people were able to accurately detect changes in entity behavior regardless of whether they were keeping track of one, two, or all three symbol attributes. However once symbol density increased beyond two symbols, people who were keeping track of two or three attributes did much worse than those keeping track of only a single attribute. Only at the highest symbol density did a person's ability to keep track of three attributes produce the worst performance, a result also consistent with those of Monty (1973) who also observed that degraded performance occurred when keeping track of changes in three categories of information.

It is interesting to note that a linear degradation in performance, as a function of symbol density, was evident only when keeping track of a single attribute; when two or more attributes were being tracked, a precipitous decline in performance occurred when symbol density increased from four to six. A similar trend for false alarm data indicated that the degradation was not only due to a failure to keep track of more symbols, but also due to a failure to remember symbol attributes from one time period to the next. It is also interesting to note that the relation between symbol density and false alarms was more linear than the relation between symbol density and hits.

There also appeared to be an asymptotic limit to the information processing time. When a change in a symbol was correctly identified, the time to respond to that change occurred within a one second window beginning about 1.25 seconds after the onset of the update. Within this response window, increasing symbol density from two to four and from four to six resulted in longer response times; increasing symbol density from six to eight did not result in an increase in response time. The search task became increasingly more complex as symbol density increased, a result most likely due to an increase in memory load requiring people to remember antecedent symbol attributes for a longer time to compare new with old. If search continued for more than two seconds, people were not able to recall the state of all symbol attributes prior to the update, and would not be able to detect a change. If true, this would place a two second limit on the time available to correctly detect a change in symbol attributes for symbol densities of six or greater. Surprisingly, the number of changing symbol attributes had little effect on response times, except in those situations where people were keeping track of a single attribute of four symbols on the display. Once symbol density increased to four symbols, those people keeping track of a single attribute were able to respond faster than those keeping track of two or three attributes. When symbol density was greater than four, no difference in response times were observed.

The type of attribute also affected performance. Keeping track of direction was decidedly more difficult than keeping track of either speed or threat class, and the difference in performance increased with increasing density. One possible explanation is that direction could take on eight possible values, while there were only two speeds and three threat classes. The same effect was found for false alarms, although there was a slight superiority of threat class over speed as well. These results suggest that both the type of attribute and number of attribute values can significantly affect performance and the memory load in a keeping track task.

The results clearly point to the importance of symbol density in keeping track performance. The remarkable outcome of this experiment was that subjects were able to effectively keep track of changes in only a very few symbols. In addition, the results with graphical symbols are consistent with other types of representations; the trends and patterns in data found in this experiment were consistent with previous research using alphanumeric representations of attribute values. Consequently, there does not appear to be any specific advantage or disadvantage for using graphical symbology, at least within the context of the task requirements of this experiment.

Relevance to the Design of Decision Support

The results of this experiment go beyond the laboratory and provide important insights into the design of decision support for tactical SA displays. The results suggest at least two important considerations for the design of such decision support.

First, it tells us that once the number of symbols to be tracked exceeds four, a significant degradation in keeping track performance will occur and that there will be a significantly higher risk of attending to symbols whose behavior has not changed. From an operational perspective, this is of particular concern. Unless the operator is handling a very limited skirmish, there is bound to be more than four entities in the tactical picture and the workload demands of the situation will rapidly exceed the operator's information processing capability (especially if the operator must perform more than this one task). Consequently, in almost any situation there will be a need to reduce the workload associated with keeping track of entities in the tactical picture. From a system design perspective, it is quite clear that the overall workload demands of the task can be reduced by introducing an automated system that can monitor symbol attributes and alert the operator to changes in the tactical picture.

Secondly, the research identifies the type and character of information that is particularly difficult to track. For instance, a symbol attribute defined by more than two or three values will be difficult to monitor when symbol density is high. This would be particularly important for attributes such as direction where heading data can take on many values and the heading of an entity is an important variable in the determination of threat potential (a hostile entity heading directly toward friendly forces is more important than one heading away). Thus a system that monitors specific changes in symbol characteristics would provide the basis for a decision aid that alerts and directs the operator's attention to the most significant threats in the tactical picture. Such a system would support the expectancy component of SA by aiding in the allocation of the operator's attention; such a mechanism would direct the operator’s attention to an entity in the tactical picture only when the behavior of that entity has changed.

In summary, then, this research has shown that the limits to keeping track performance found in theoretical research are relevant to actual battlefield tasks, and that those limits have important implications for the design of tactical displays. Although graphical symbols appear to be an acceptable method for representing entity attributes and behavior, the limits to keeping track performance found in this and other research suggest that some form of decision aiding will be required to enhance SA and significantly reduce the overall workload demands of the task.

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